Next Generation Photovoltaic Devices and Processes Selections

DOE Solar Energy Technologies Program

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For Media Information, Contact: kevin.brosnahan@ee.doe.gov

For Technical Information, Contact: marie.mapes@ee.doe.gov

Next Generation Photovoltaic Devices and Processes Objectives

Provide funding to bridge the gap between basic and applied solar research

- Develop solar energy science into new photovoltaic technologies
- Focus on delivery of devices and processes with confirmed performance through yearly milestones

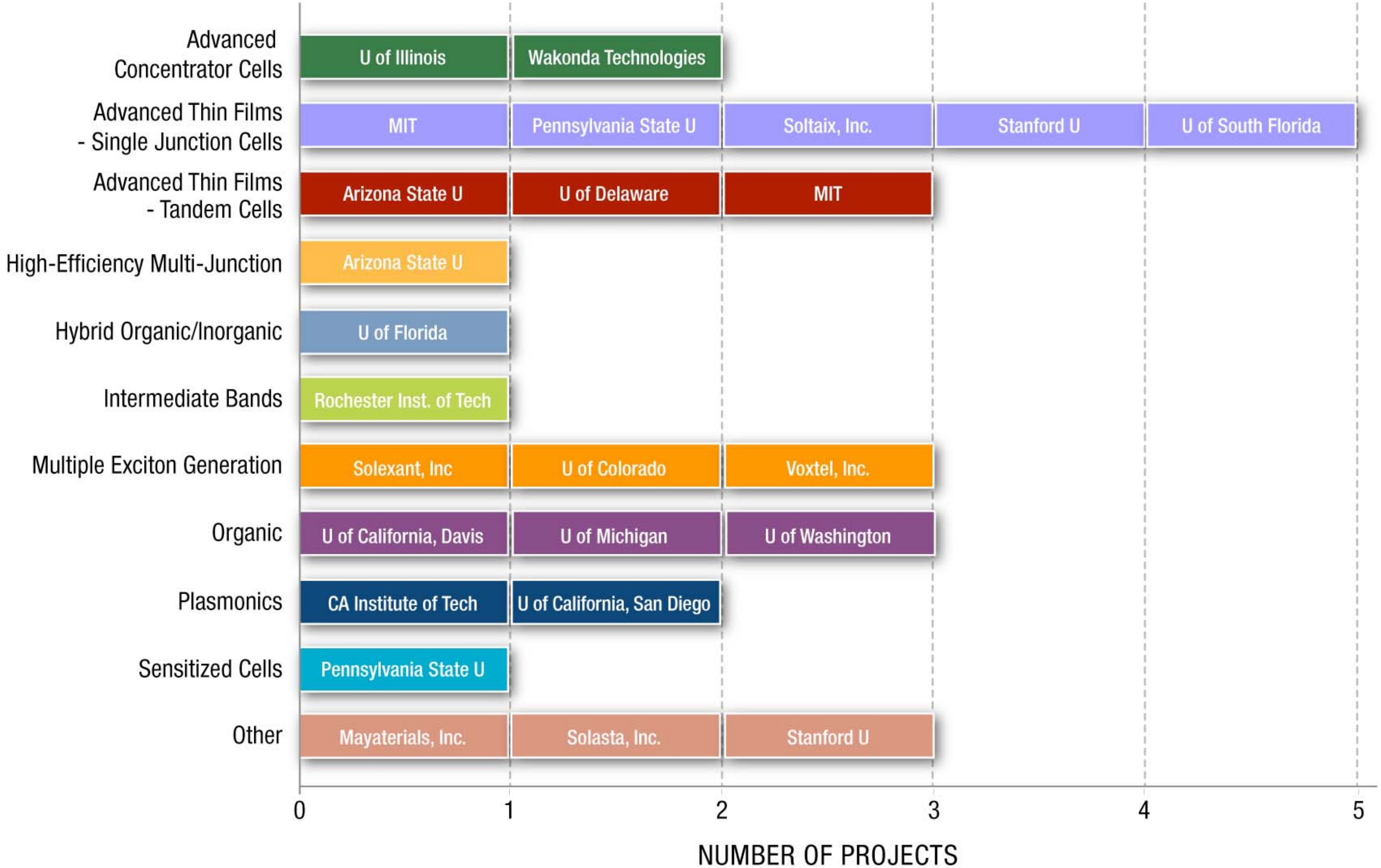
Seed the beginning of the technology pipeline with high payoff projects

- Initiate innovative, revolutionary, and highly disruptive PV approaches that could drastically change the solar market's paradigm if successful
- Produce prototype cells and/or processes by 2015, with full commercialization coming to fruition in the 2020-2030 time-frame

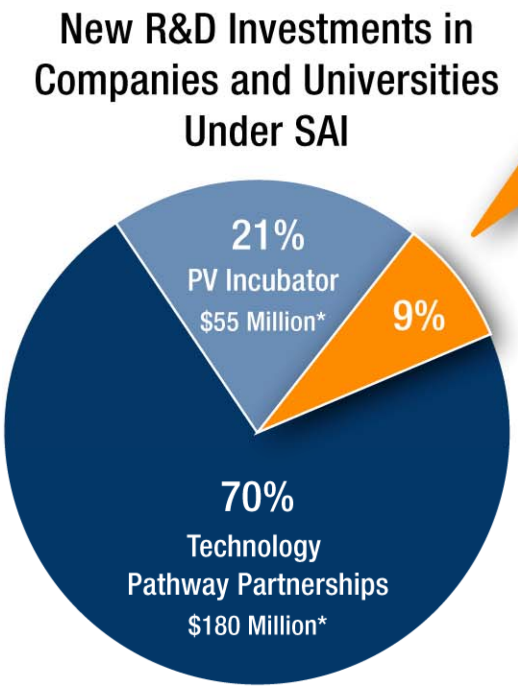
Lay the framework to exceed the goals of the Solar America Initiative

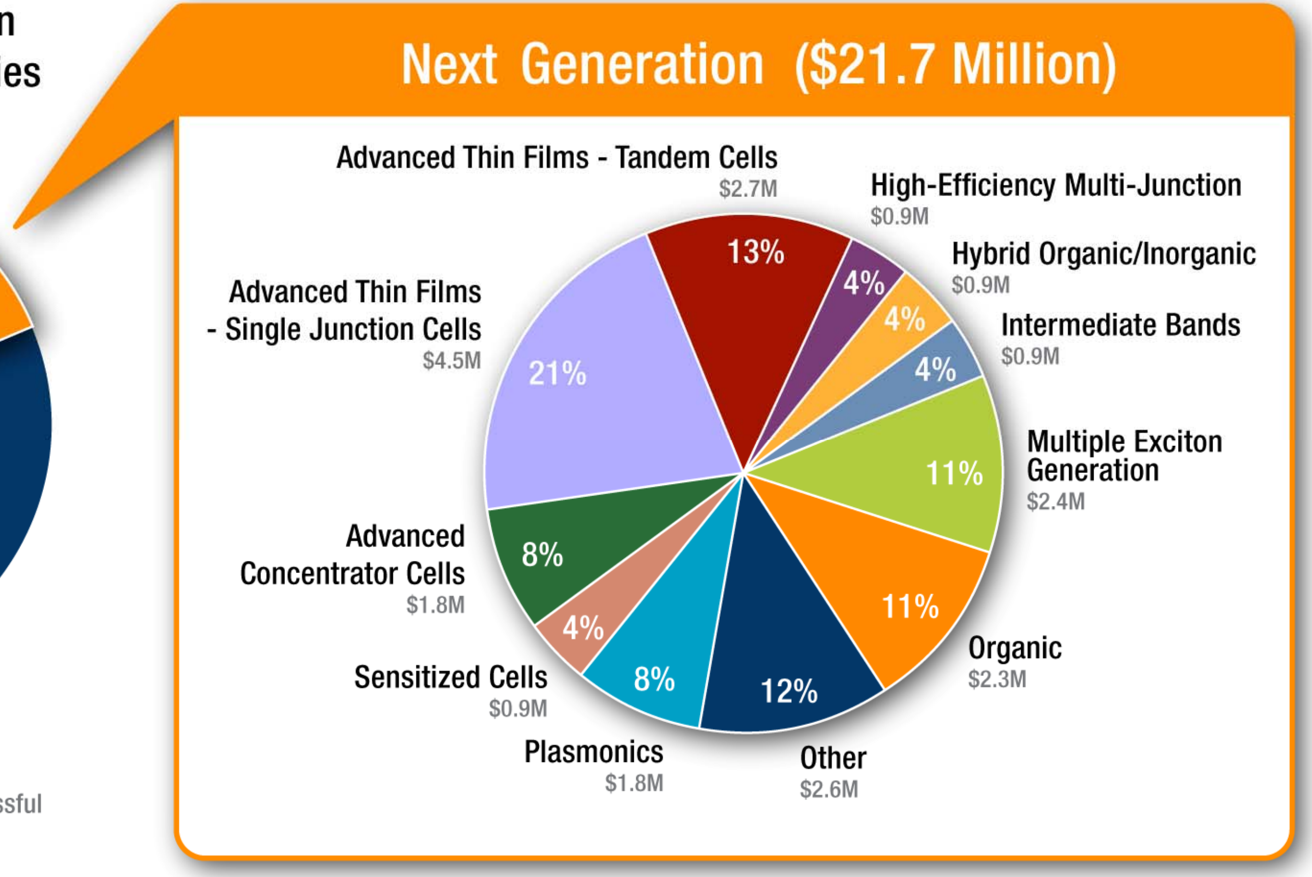
- Fund projects for PV technologies that have the potential to be significantly less expensive than grid electricity
- Ensure availability of new technologies to capitalize on SAI success post-2015, positioning solar to be the economical solution for baseload national energy consumption

DOE's Next Generation PV Projects are a technologically diverse portfolio



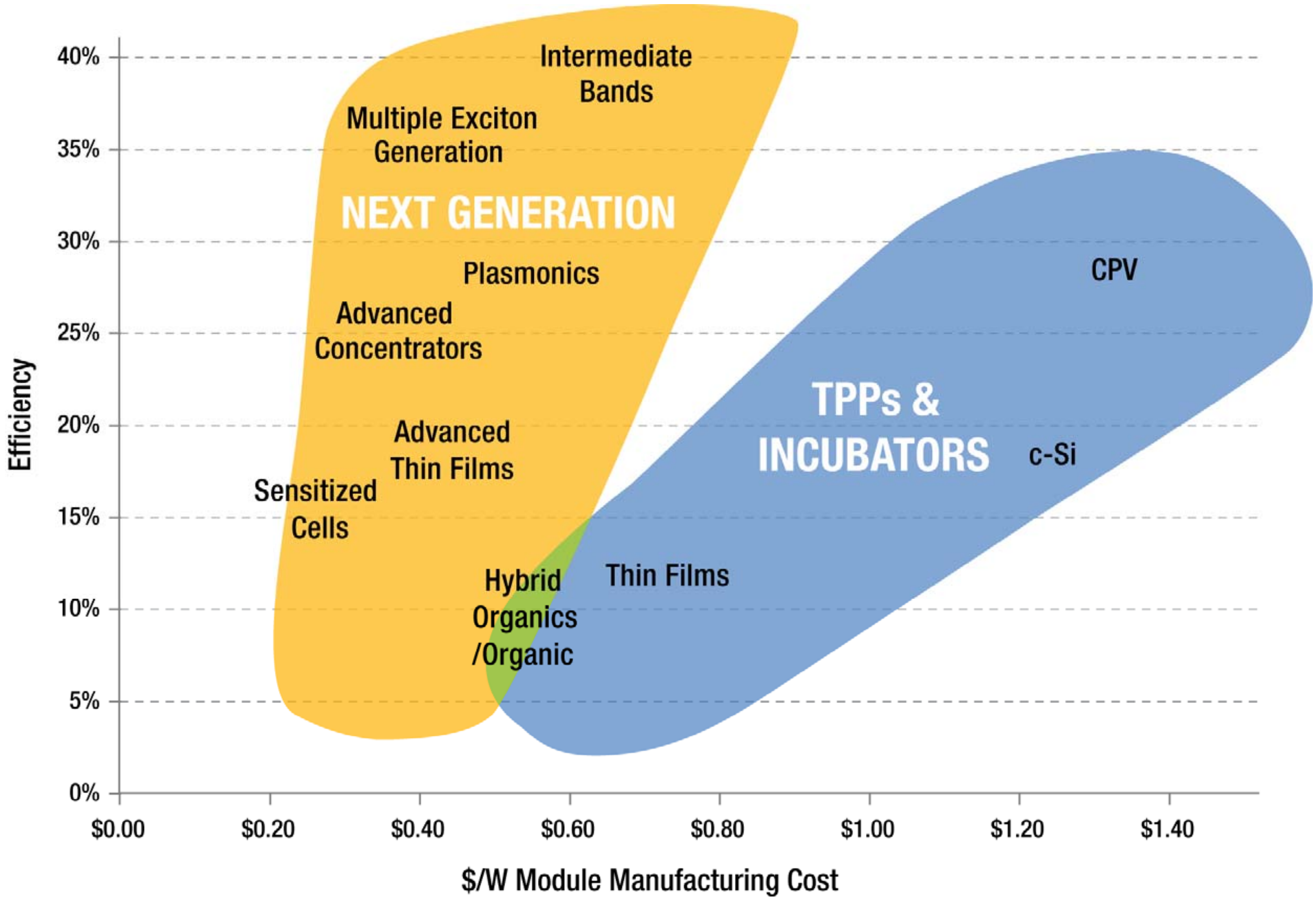
Next Generation PV supports many small seed projects that have high payoff potential





* Numbers shown are based upon successful completion of performance milestones.

Next Generation PV Projects will expedite improvements in efficiency and lower the costs of developing PV technology



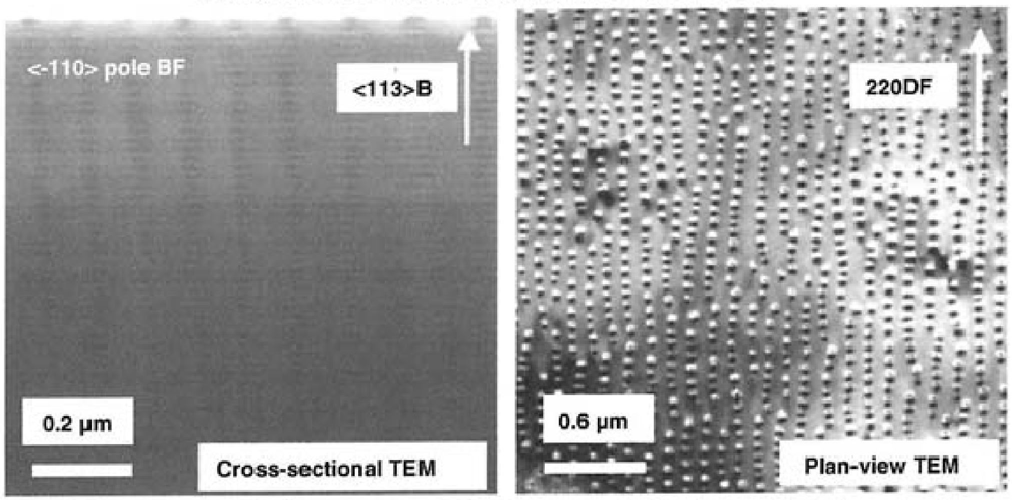
Next Generation PV Workforce Development: the photovoltaic industry will have access to a new pool of students gaining employable skills in advanced PV technology

Arizona State U	Tempe, Arizona	Solexant, Inc.	Sunnyvale, CA	U of Florida	Gainesville, FL
CA Institute of Tech	Pasadena, CA	Soltaix, Inc.	Los Altos, CA	U of South Florida	Tampa, FL
Mayaterials, Inc.	Ann Arbor, MI	Stanford U	Stanford, CA	U of Illinois	Urbana, IL
MIT	Cambridge, MA	U of California, San Diego	La Jolla, CA	U of Michigan	Ann Arbor, MI
Pennsylvania State U	University Park, PA	U of California, Davis	Davis, CA	U of Washington	Seattle, WA
Rochester Institute of Tech	Rochester, NY	U of Colorado	Boulder, CO	Voxtel, Inc.	Beaverton, OR
Solasta, Inc.	Newton, MA	U of Delaware	Newark, Delaware	Wakonda Technologies	Fairport, NY

Next Generation PV Technologies

Nano-Architecture

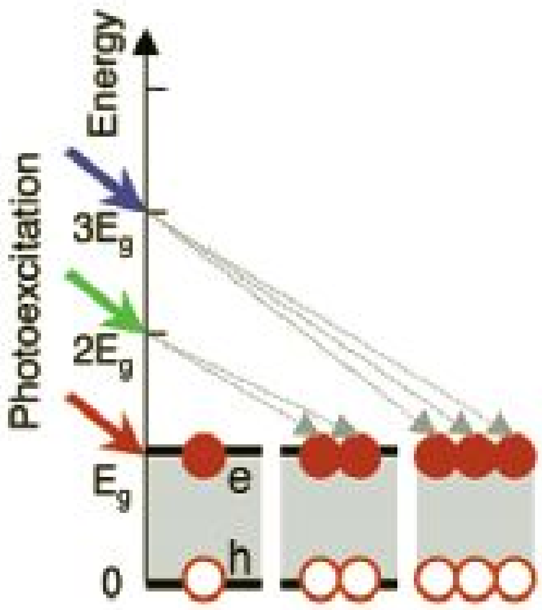
MOCVD Growth of InGaAs/ QD arrays on (113)B GaAs substrates for intermediate band solar cells



- QD arrays are being grown to test concept of intermediate band solar cell proposed by A. marti and A. Luque

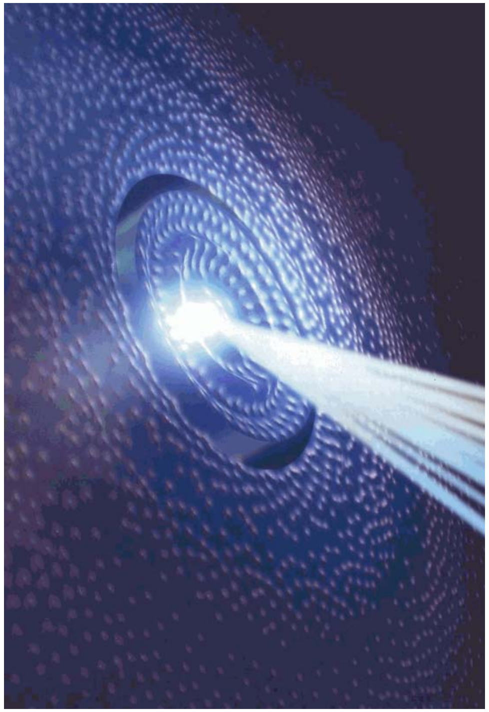
Nano-architecture solar cells use materials or structures sized at the 1-100 nanometer length scale as photon absorbers or exciton transporters. Unique quantum effects can result, such as the creation of quantum wells from carefully arranging the nanostructure of a device or bandgap tuning using quantum dots of particular sizes and compositions. The potential for nanowires to serve as photon ballistic waveguides is also being explored, where photons travel inside the tube and electrons travel on the outside shell. Advantages in manufacturing with solution-dispersible nanomaterials are also a possibility; for example, atmospheric processing of nanowire electrical contacts and quantum dot absorber layers.

Multiple Exciton Generation



Multiple exciton generation (MEG) is the generation of multiple excitons for each photon of sufficient energy that is absorbed by the photovoltaic cell. MEG raises the theoretical attainable power conversion efficiency of a single-junction photovoltaic solar cell from 33.7% to 44.4%. Inorganic semiconductor nanocrystals, such as spherical quantum dots, quantum rods, or quantum wires, have the potential to improve bulk semiconductor cell efficiencies via MEG.

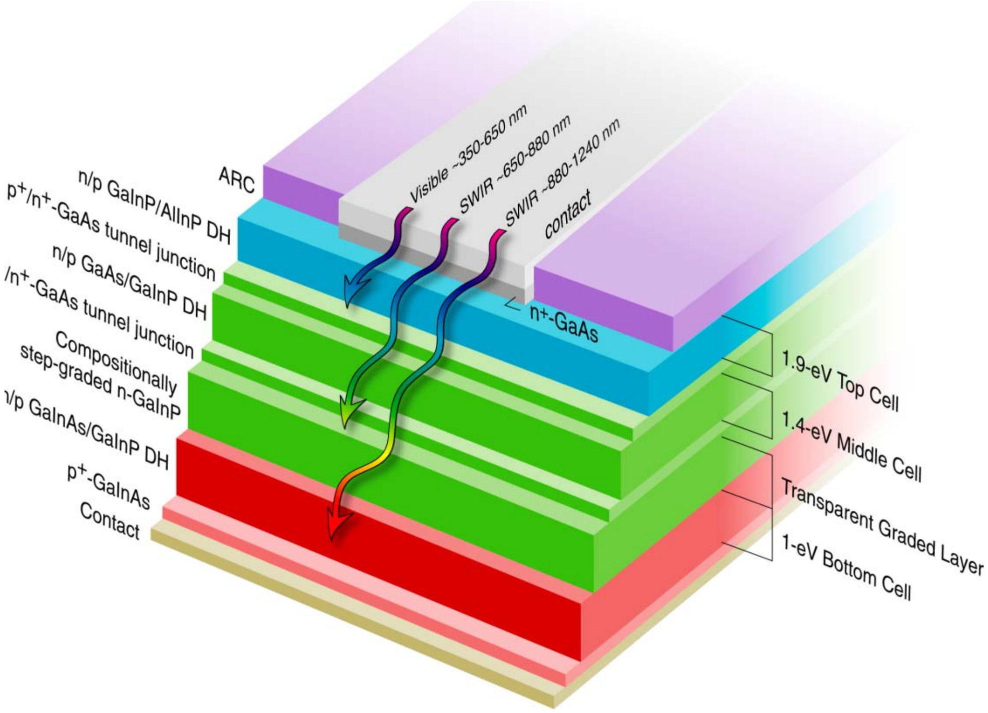
Plasmonics



Artist's rendering of plasmons created by light striking the surface of a metal. Scientific American. April 2007.

Plasmonics is an emerging branch of photonics that uses nanostructured materials to control light, and as applied to photovoltaics, enable more light to enter the absorber. Plasmons are density waves of electrons, created when light hits the surface of a metal under precise circumstances. These density waves couple light into a PV cell that would not otherwise be absorbed, increasing light absorption and therefore PV cell performance.

Tandems



Tandem cells, also called multijunction cells, are individual cells with different bandgaps stacked on top of one another. The individual cells are stacked so that sunlight falls first on the material having the largest bandgap. Photons not absorbed in the first cell are transmitted to the second cell, which then absorbs the higher-energy portion of the remaining solar radiation while remaining transparent to the lower-energy photons. While current multijunction III-V concentrator cells are proven successes of this approach, Future Generation PV projects address the challenge of finding less expensive methods of making tandem cells.

Next Generation PV Technologies Selections

Arizona State University

Dr. John Kouvetakis

Advanced Semiconductor Materials for Breakthrough Photovoltaic Applications

Technologies Addressed
High-Efficiency Multi-Junction

Description
To demonstrate the fundamental viability of new semiconductor materials with a potential for disruptive breakthroughs in photovoltaics.

Target Efficiency	NA

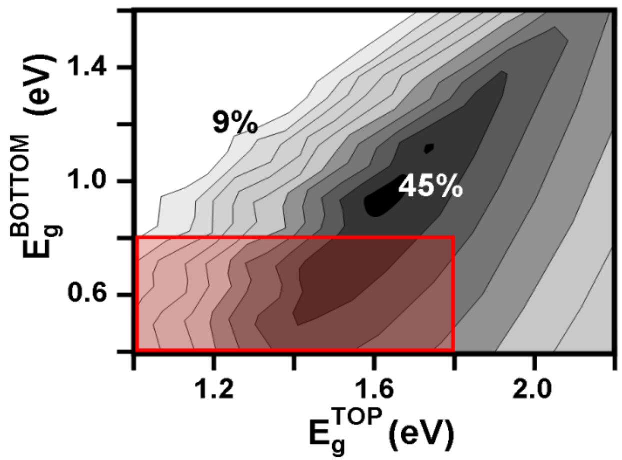


Figure 1: Iso-efficiency plots (based on calculations of Meillaud) for the upper thermodynamic limit efficiency of 2-junction cells. The red shaded rectangle corresponds to the region of interest for thin Si/GeSn solar cells.

Resources ($)		
Total Project	DOE Funds	Cost Share
$1,287,824	**$881,152**	**$406,672**

Arizona State University

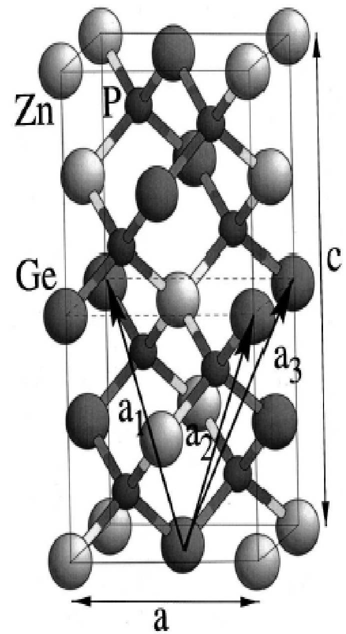
Dr. Marc van Schilfgaarde

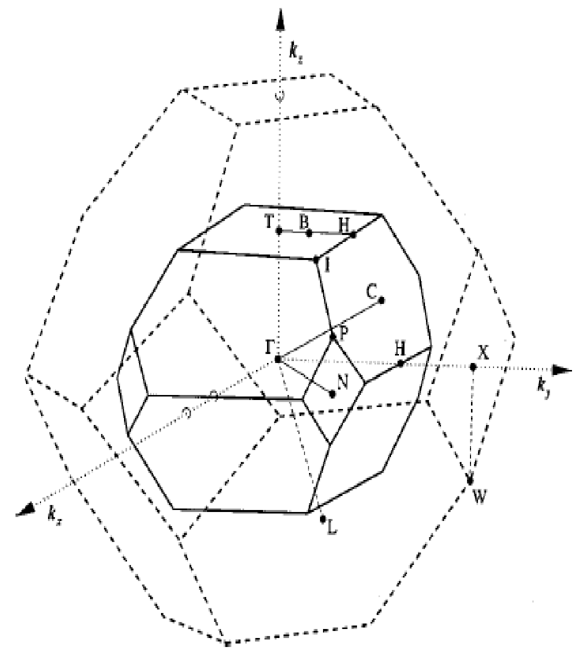
II-IV-V Based Thin Film Tandem Photovoltaic Cell

Technologies Addressed
Advanced Thin Films – Tandem Junction

Description
Development of materials for II-IV-V based tandem thin film cells, starting with $ZnSnP_2$ and $ZnGeAs_2$, to push 20% efficiency.

Target Efficiency	**20% 2010**





Resources ($)		
Total Project	DOE Funds	Cost Share
$1,136,345	**$895,511**	**$240,834**

California Institute of Technology

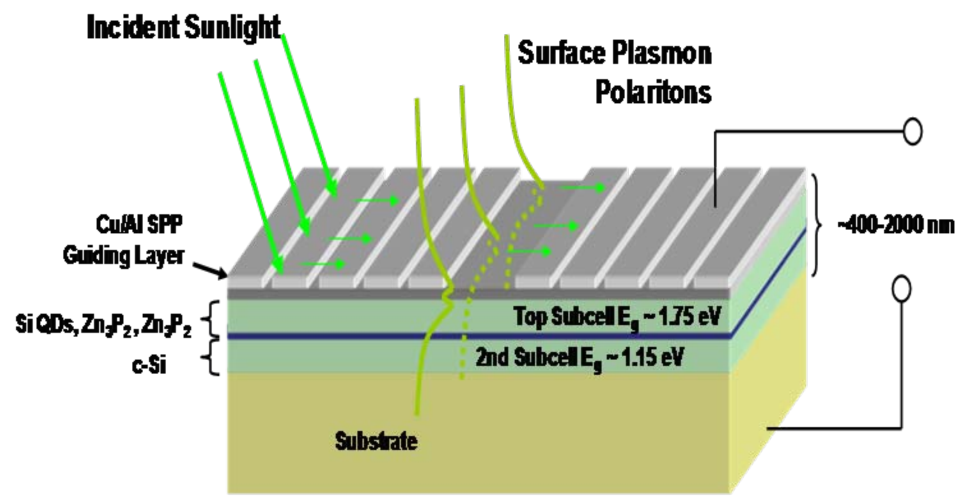
Dr. Harry Atwater

Solar Cells from Earth-Abundant Semiconductors with Plasmon-Enhanced Light Absorption

Technologies Addressed
Plasmonics

Description
Plasmonic light absorption in earth-abundant semiconductors (quantum dots, and Zn_3P_2). A top cell with earth abundant absorber will be integrated with a Si bottom cell.

Target Efficiency	25%



Resources ($)		
Total Project	DOE Funds	Cost Share
$1,125,000	**$900,000**	**$225,000**

Massachusetts Institute of Technology

Dr. Vladimir Bulovic

All-Inorganic, Efficient Photovoltaic Solid State Devices Utilizing Semiconducting Colloidal Nanocrystal Quantum Dots

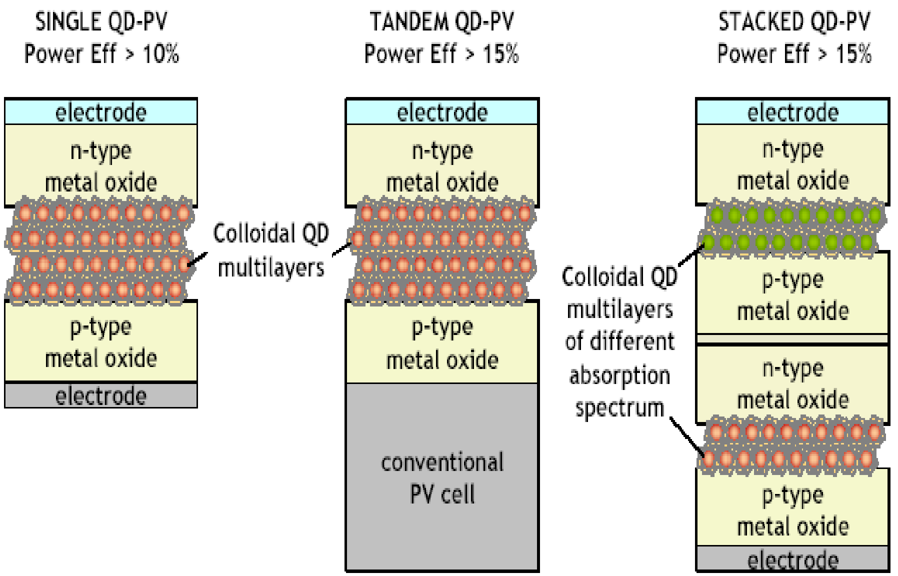
Technologies Addressed

Advanced Thin Film – Tandem Junction

Description

Tuneable bandgap using Cd or Pb quantum dots. Tandem devices are made by putting quantum dots on top of a conventional cell or mechanically stacking quantum dot cells with different bandgaps. Solution processible for low cost photovoltaics.

Target Efficiency	**15% 2010**



Resources ($)

Total Project	DOE Funds	Cost Share
$1,125,000	**$900,000**	**$225,000**

Massachusetts Institute of Technology

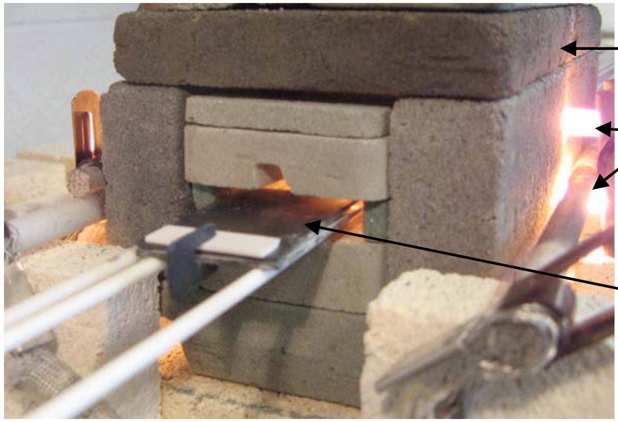
Dr. Emanuel Sachs

Thin, High Lifetime Silicon Wafers with No Sawing; Recrystallization in a Thin Film Capsule

Technologies Addressed
Advanced Thin Films – Single Junction

Description
To create a silicon wafer-making technology that will set a new standard by combining high electronic quality and low cost.

Target Efficiency	>20%



Insulation

Heaters

Sandwich of backing plates, wafer in capsule and powder layers for release.

Resources ($)		
Total Project	DOE Funds	Cost Share
$1,088,874	**$899,998**	**$188,876**

Mayaterials, Inc.

Dr. Richard Laine

Solar Grade Silicon From Agricultural By-Products

Technologies Addressed
Silicon Feedstock

Description
Polysilicon solar cell feedstock derived from agricultural by-product streams without the Siemens process. With anticipated energy contents and production costs equal to or lower than conventional methods

Target Efficiency	**< $25/kg**

Rice hulls contain up to 20 wt % SiO_2

Resources ($)		
Total Project	DOE Funds	Cost Share
$1,065,799	**$837,000**	**$228,799**

Pennsylvania State University

Dr. Harry Allcock

Improved Electrodes and Electrolytes for Dye-Based Solar Cells

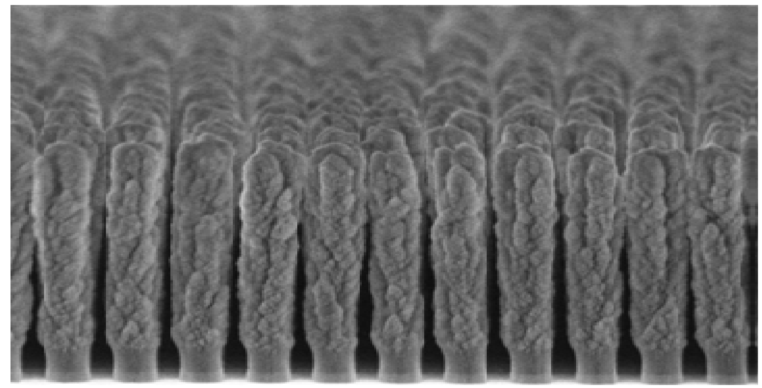
Technologies Addressed

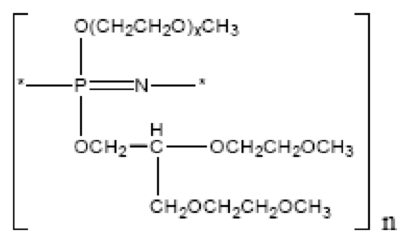
Sensitized Cell

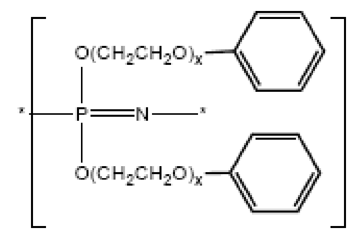
Description

Graetzel cell with polyphosphazene polymer gel electrolyte, used in lithium ion batteries, intercalated between TiO2 columns.

Target Efficiency	15-20% 2010







Resources ($)

Total Project	DOE Funds	Cost Share
$1,058,531	**$882,103**	**$176,428**

Pennsylvania State University

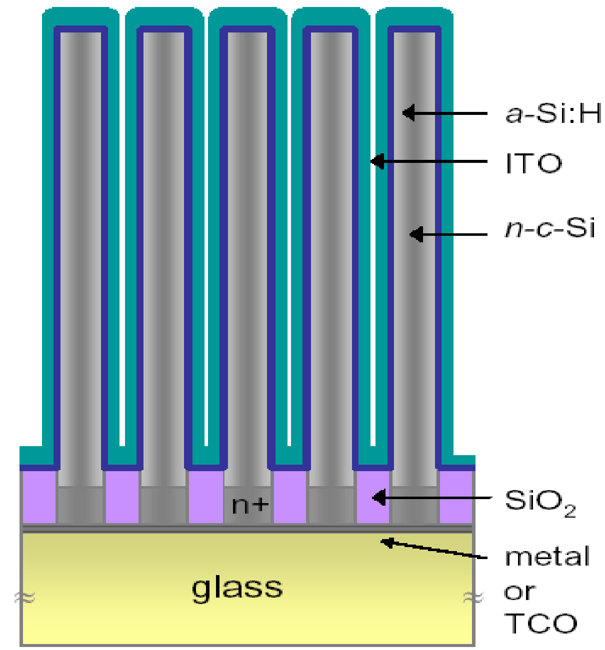
Dr. Joan Redwing

High Aspect Ratio Semiconductor Heterojunction Solar Cells

Technologies Addressed
Advanced Thin Films – Single Junction

Description
Photovoltaic devices made from radial single junction a-Si/nc-Si nanowires grown on inexpensive substrates like glass.

Target Efficiency	15% 2010



Resources ($)		
Total Project	DOE Funds	Cost Share
$1,125,00	**$900,000**	**$225,000**

Rochester Institute of Technology

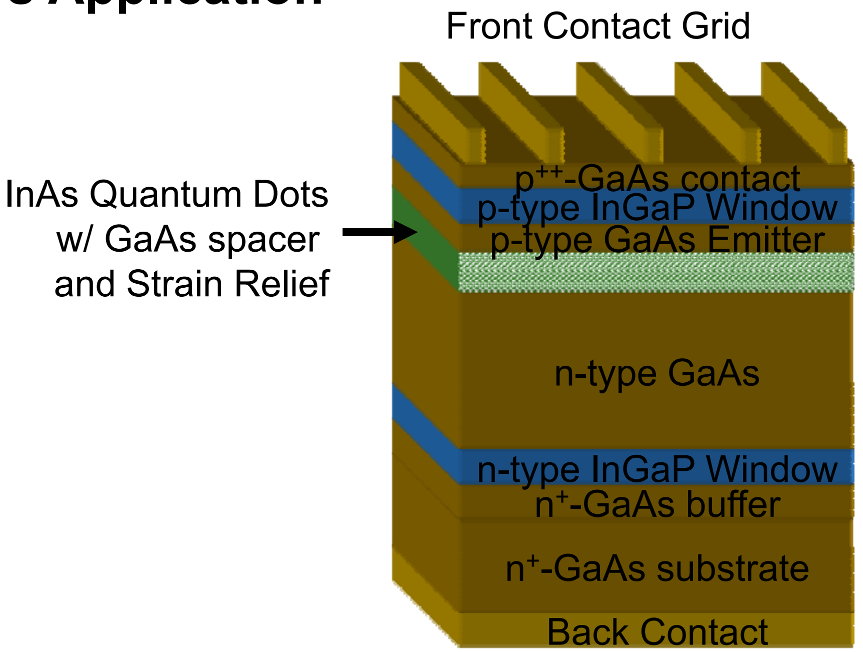
Dr. Seth Hubbard

High Efficiency Nanostructured III-V Photovoltaics for Solar Concentrators Application

Technologies Addressed
Intermediate Band Solar Cell

Description
InAs quantum dots incorporated into the GaAs cell of a multijunction III-V device to enhance IR absorption in the near term and provide initial insight into intermediate band cells in the long term.

Target Efficiency	40%



Design of GaAs quantum dot enhanced *pin* solar cell

Resources ($)		
Total Project	DOE Funds	Cost Share
$1,115,857	**$843,695**	**$272,162**

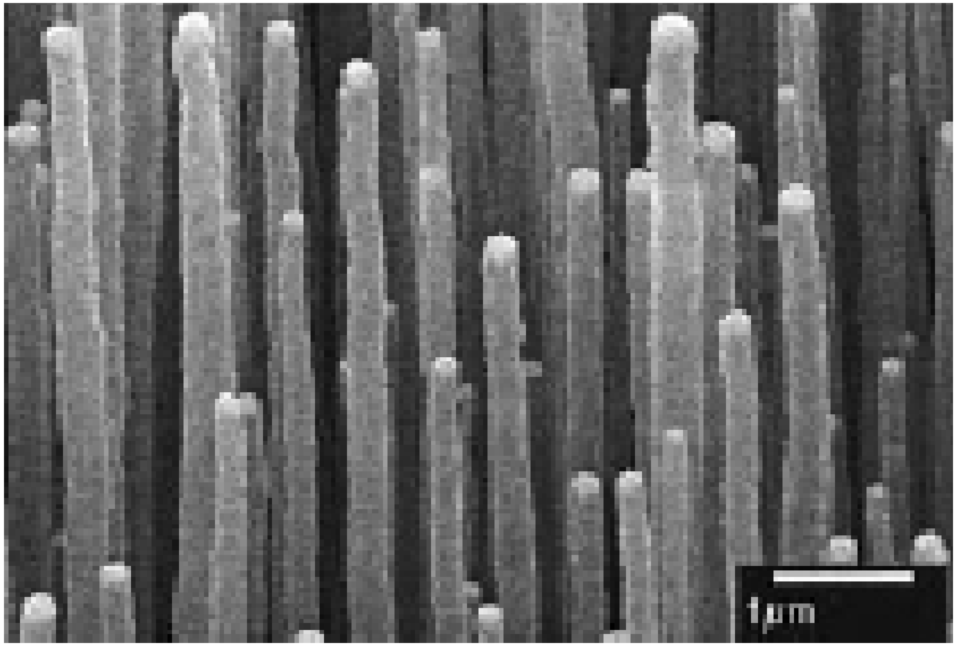
Solasta, Inc.

Dr. Michael Naughton

High Efficiency Solar Power via Separated Photo and Voltaic Pathways

Technologies Addressed

Other Thin Film Approaches



Description

Nanostructures of carbon nanotubes, PV absorber material (a-Si), and metal to make nanoengineered solar cells, which separates the path of the photons from the path of the generated charge carriers.

Target Efficiency	25% 2010

Resources ($)

Total Project	DOE Funds	Cost Share
$1,800,000	**$900,000**	**$900,000**

Solexant, Inc.

Dr. Alison Breeze

High Efficiency Quantum Dot Solar Cells Based on Multiple Exciton Generation

Technologies Addressed
Multiple Exciton Generation

Description
To demonstrate that the efficient multiple exciton generation observed in quantum dot materials can be harvested in nanostructured solar cells to dramatically improve the maximum power efficiency obtainable in photovoltaic modules.

Target Efficiency	>31%

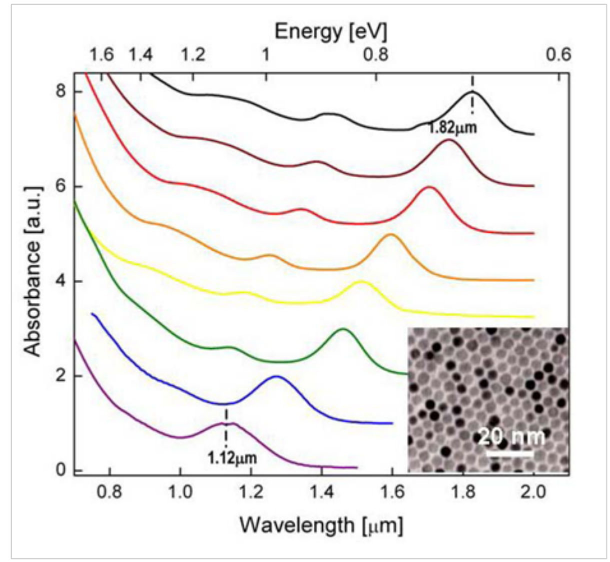


Figure 4: The absorbance shift for PbSe quantum dots (2.5 to 5.8 nm). Inset: TEM of PbSe quantum dots (~5.2 nm).

Resources ($)		
Total Project	DOE Funds	Cost Share
$1,109,035	**$869,435**	**$239,600**

Soltaix, Inc.

Dr. Mehrdad Moslehi

Feasibility Demonstration and Performance Optimization of a Disruptive Ultra-High-Efficiency, Thin-Film, Crystalline Silicon Solar Cell for Cost-Effective, Grid-Connected Electricity

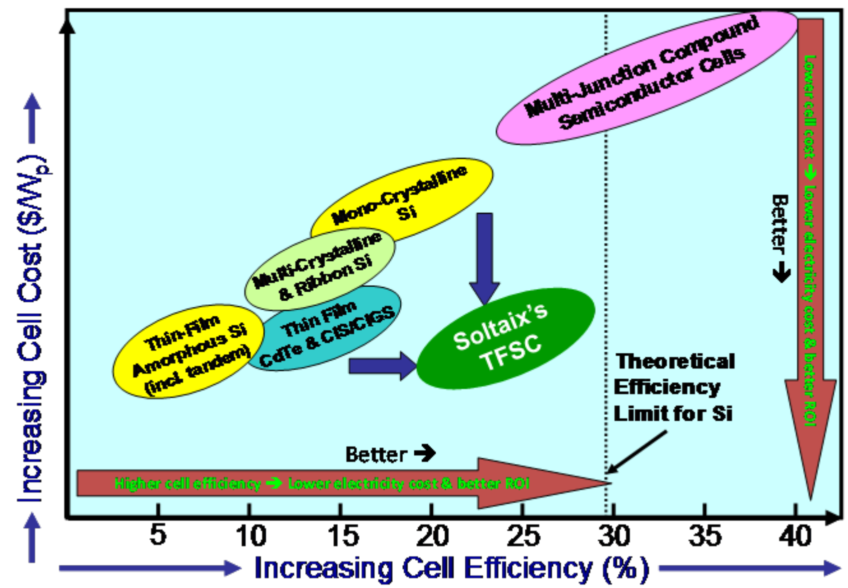
Technologies Addressed

Advanced Thin Films – Single Junction

Description

Use of thin film Si absorber layer for high-efficiency cells with efficient light trapping and reduced Si usage. The technical approach removes dependency of cell manufacturing on the traditional Si wafer supply chain.

Target Efficiency	**21% 2010**



Resources ($)

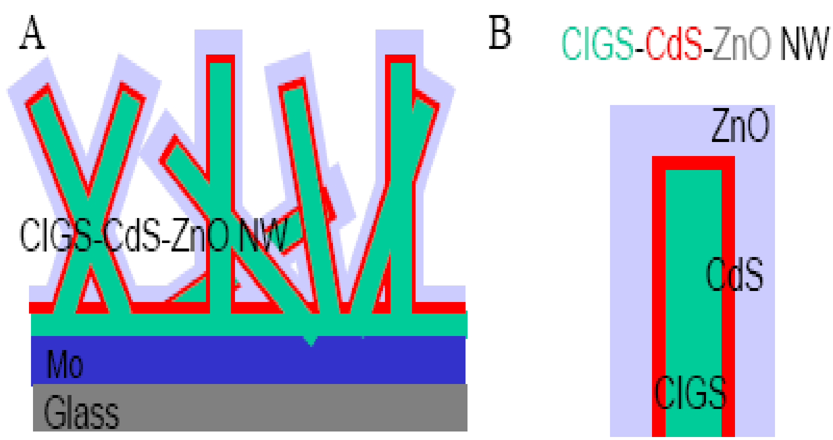
Total Project	DOE Funds	Cost Share
$1,800,000	**$900,000**	**$900,000**

CuIn (Ga) Se2 (CIGS) Nanowire Solar Cells

Technologies Addressed
Advanced Thin Films – Single Junction

Description
Production of inorganic nanostructured thin film solar cells made of CIGS nanowires with diameters less than 200 nm.

Target Efficiency	30% 2010



Resources ($)

Total Project	DOE Funds	Cost Share
$1,125,000	**$900,000**	**$225,000**

Stanford University

Dr. Peter Peumans

Nanostructured Materials for High Efficiency Low Cost Solution-Processed Photovoltaics

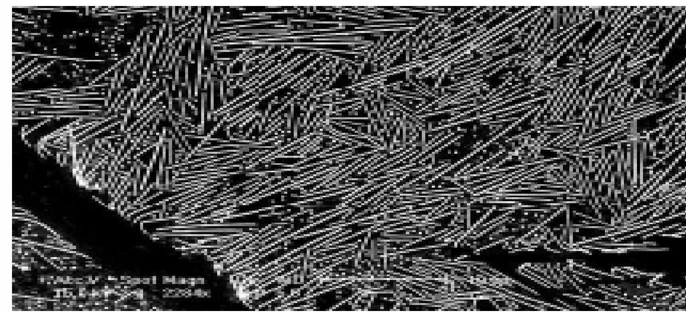
Technologies Addressed

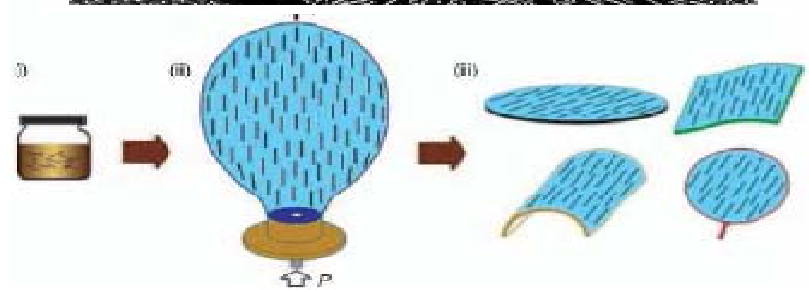
Alternate Contact Technology

Description

Ordered ZnO nanowire networks or Ag nanowire meshes for low cost contacts. Solution processing into ordered networks through bubble expansion of nanowire/polymer suspension.

Target Efficiency	**NA**





Resources ($)

Total Project	DOE Funds	Cost Share
$1,125,002	**$900,000**	**$225,002**

University of California, Davis

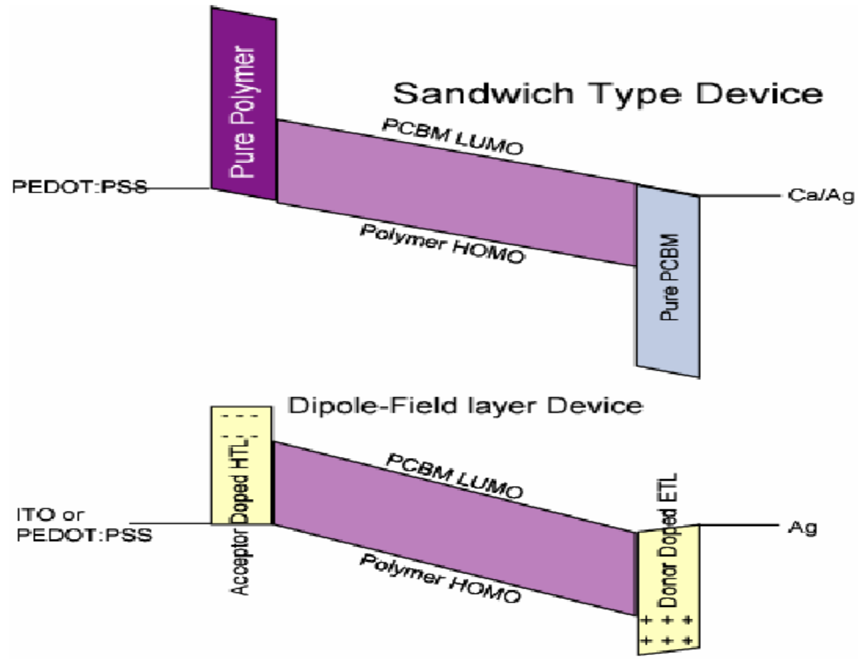
Dr. Adam Moule

Functional Multi-layer Solution Processable Polymer Solar Cells

Technologies Addressed
Organic Photovoltaics

Description
Organic photovoltaics made from of multiple polymer films with electron-only, hole-only and interface dipole layers. A gel protection layer allows for spin coating of the multiple polymer films. Solution processible for low cost photovoltaics.

Target Efficiency	7% 2010



Resources ($)		
Total Project	DOE Funds	Cost Share
$767,685	**$610,916**	**$156,769**

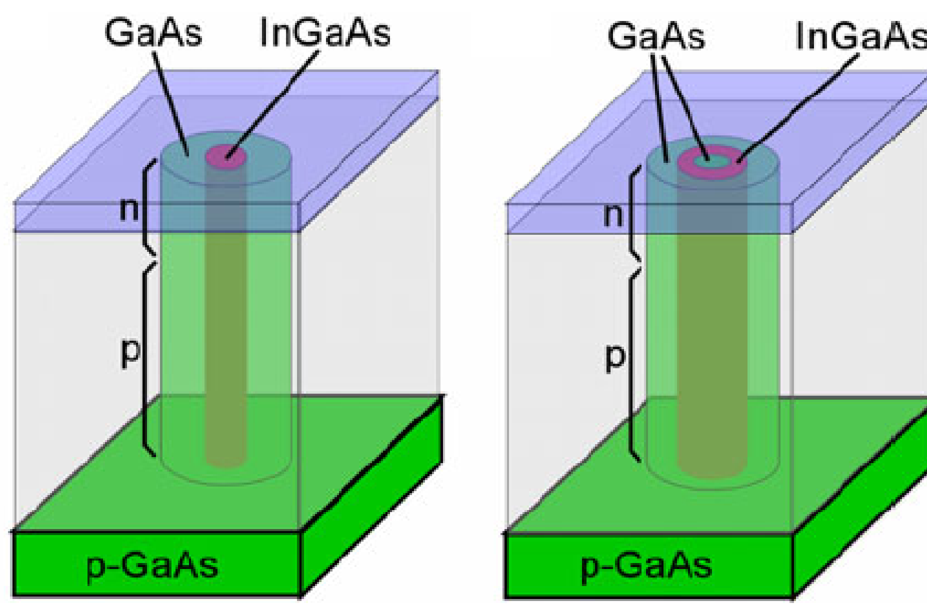
University of California, San Diego

Dr. Edward Yu

High-Efficiency Photovoltaics Based on Semiconductor Nanostructures

Technologies Addressed
Plasmonics

Description
Researchers will produce high-efficiency photovoltaics that combine plasmonics and III-V quantum well and nanowire solar cells.



Target Efficiency	NA

Resources ($)		
Total Project	DOE Funds	Cost Share
$1,125,000	**$900,000**	**$225,000**

University of Colorado

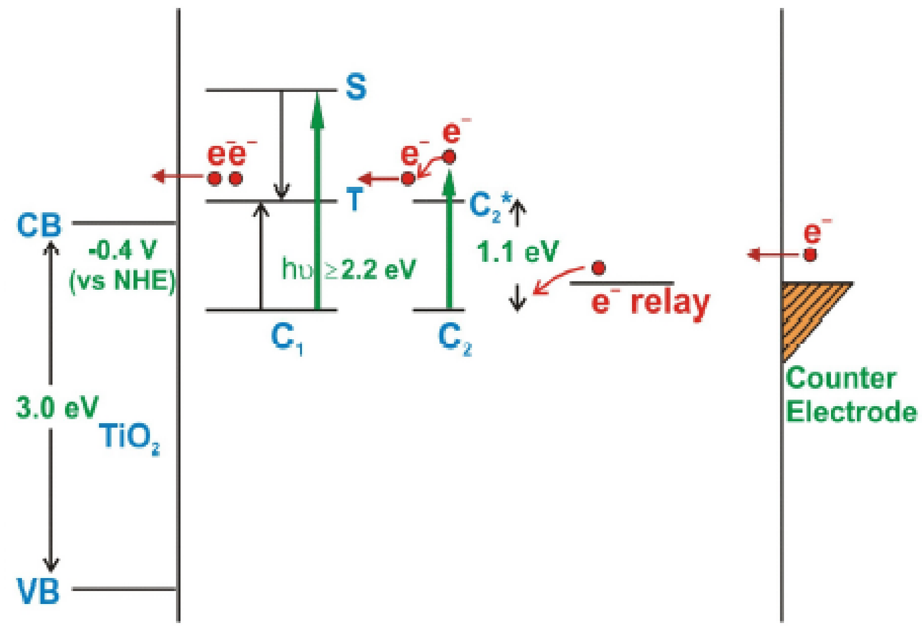
Dr. Josef Michl

Exciton Fission for an Ultra-High Efficiency, Low Cost Solar Cell

Technologies Addressed
Multiple Exciton Generation

Description
Graetzel cell that will use dye molecules and nanocrystals of dye to produce multiple electrons from one photon of light.

Target Efficiency	45%



Resources ($)		
Total Project	DOE Funds	Cost Share
$1,119,715	**$895,772**	**$223,943**

University of Delaware

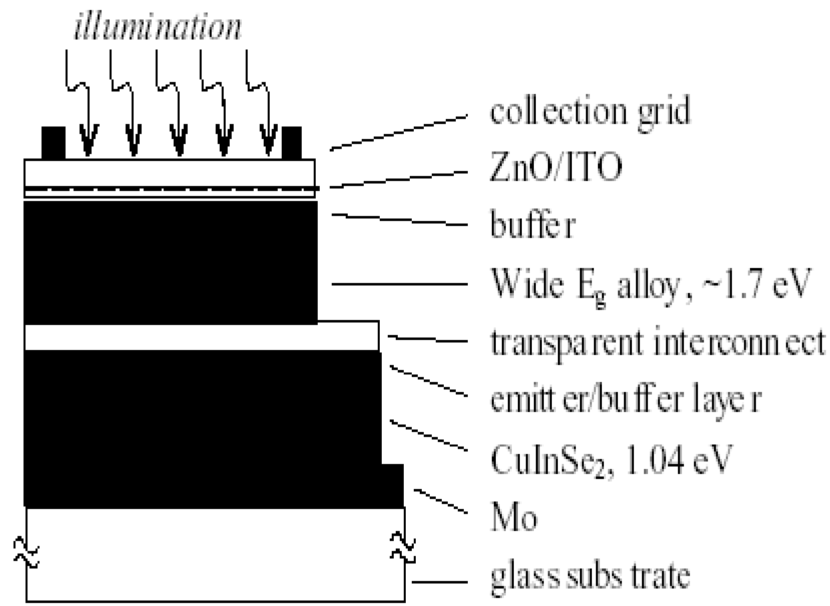
Dr. William Shafarman

Novel Approaches to Wide Bandgap $CuInSe_2$-Based Solar Cells

Technologies Addressed
Advanced Thin Films –Tandem Junction

Description
Development of a highly efficient, wide bandgap, $CuInSe_2$ chalcopyrite-based solar cell, which is necessary for polycrystalline tandem devices. Laser processing will be used to control defects, which will improve the performance of the cell.

Target Efficiency	15% (single jn) 2010



Resources ($)

Total Project	DOE Funds	Cost Share
$1,163,315	**$900,000**	**$263,315**

University of Florida

Dr. Jiangeng Xue

Very High Efficiency Hybrid Organic-Inorganic Photovoltaic Cells

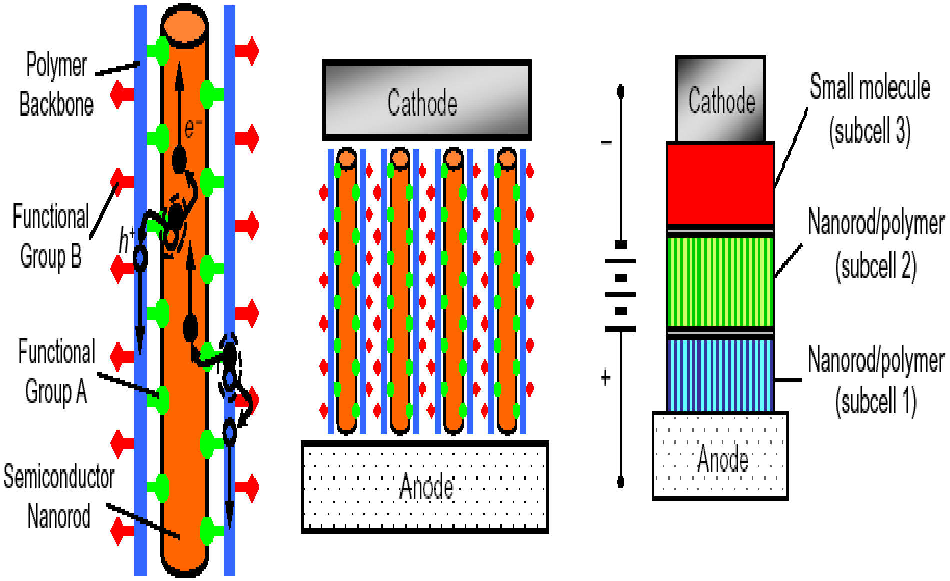
Technologies Addressed

Hybrid Inorganic/Organic Photovoltaics

Description

Aligned, inorganic ternary alloy nanorods with tuned bandgaps combined with organic polymer hole conduction media arranged in tandem devices. Solution processible for low cost photovoltaics.

Target Efficiency	**12% 2010; 25% 2015**



Resources ($)

Total Project	DOE Funds	Cost Share
$1,125,000	**$900,000**	**$225,000**

University of Illinois

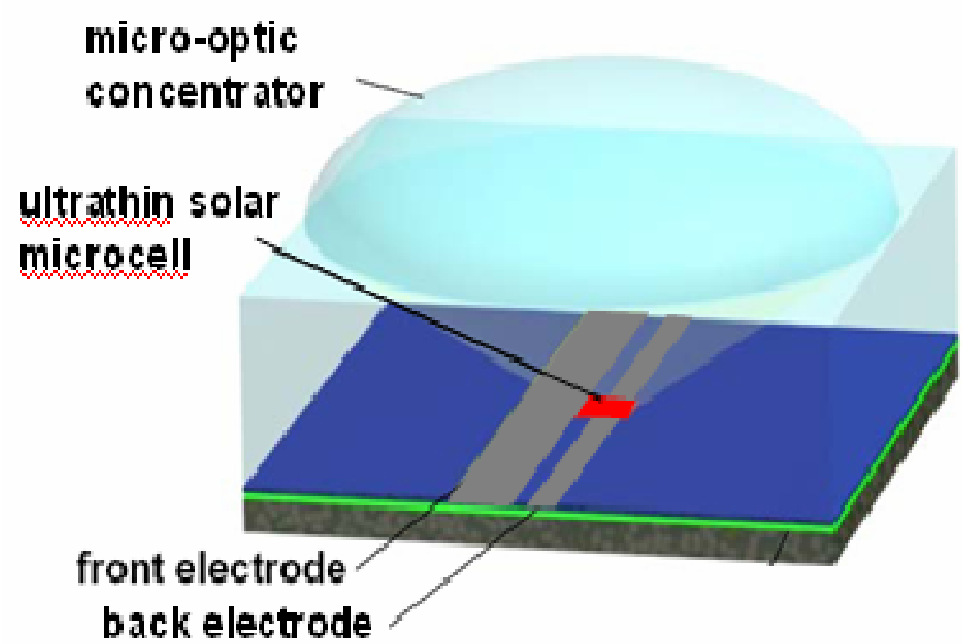
Dr. John Rogers

Transfer Printed Microcells with Micro-Optic Concentrators for Low Cost, High Performance Photovoltaic Modules

Technologies Addressed
Advanced Concentrators

Description
Transfer printing to distribute large numbers (>250,000) of GaAs microcells with molded, micro-optic concentrators over large area foreign substrates, interconnected with direct ink writing.

Target Efficiency	25% module 2010



Resources ($)

Total Project	DOE Funds	Cost Share
$1,125,000	**$900,000**	**$225,000**

University of Michigan

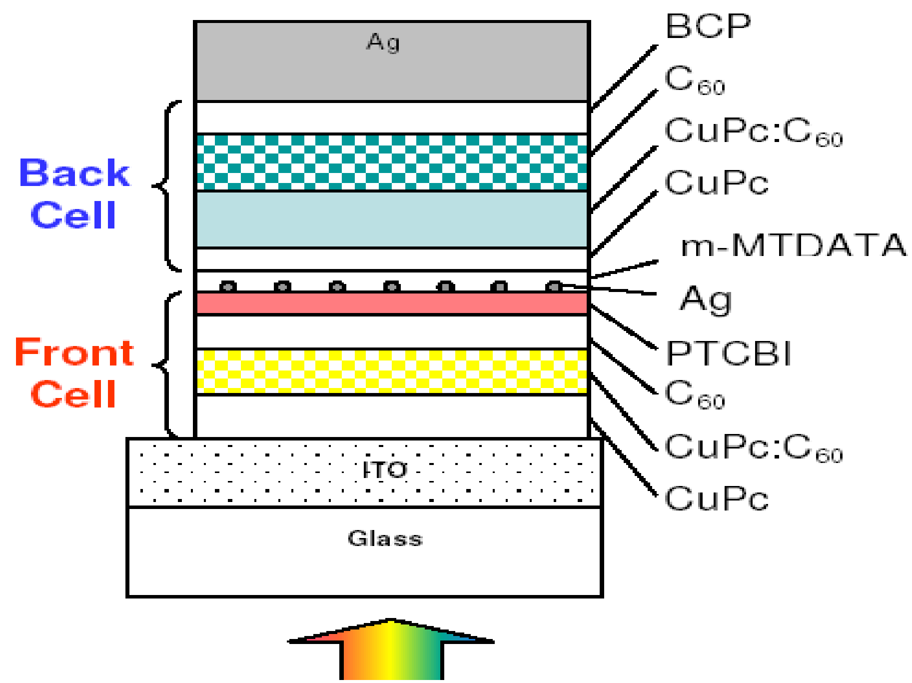
Dr. Stephen Forrest

Crystalline Organic Photovoltaic Cells

Technologies Addressed
Organic Photovoltaics

Description
Organic, small molecule planar hetero-junction, tandem cells utilizing the crystalline physical form.

Target Efficiency	10% 2010



Resources ($)		
Total Project	DOE Funds	Cost Share
$948,059	**$790,049**	**$158,010**

University of South Florida

Dr. Christos Ferekides

Next Generation CdTe Technology Substrate Foil-Based Solar Cells

Technologies Addressed
Advanced Thin Films – Single Junction

Description
To transform the standard process/product design of CdTe cells and modules from a glass-to-glass superstrate configuration, into a metallic foil substrate configuration using close-spaced sublimation, a high throughput process.

Target Efficiency	13%

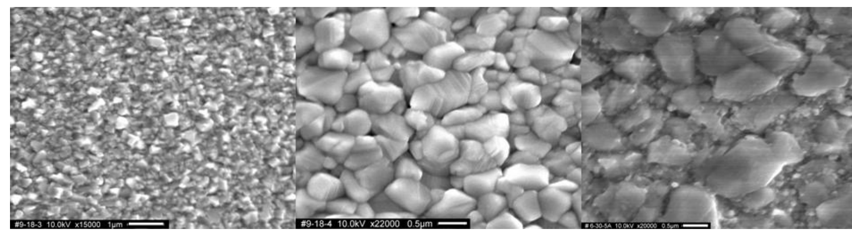


Figure 5. SEM images for ZnTe (left), CdTe (center), and CdS (right); all films deposited on SS substrates using CSS. The white scale bars at the bottom of each image correspond to 1.0 μm for ZnTe, 0.5 μm CdTe, and 0.5 μm CdS.

Resources ($)		
Total Project	DOE Funds	Cost Share
$1,154,966	**$881,927**	**$272,994**

University of Washington

Dr. Alex Jen

Interfacial Engineering for Highly Efficient π-Conjugated Polymer-Based Bulk Heterojunction Photovoltaic Devices

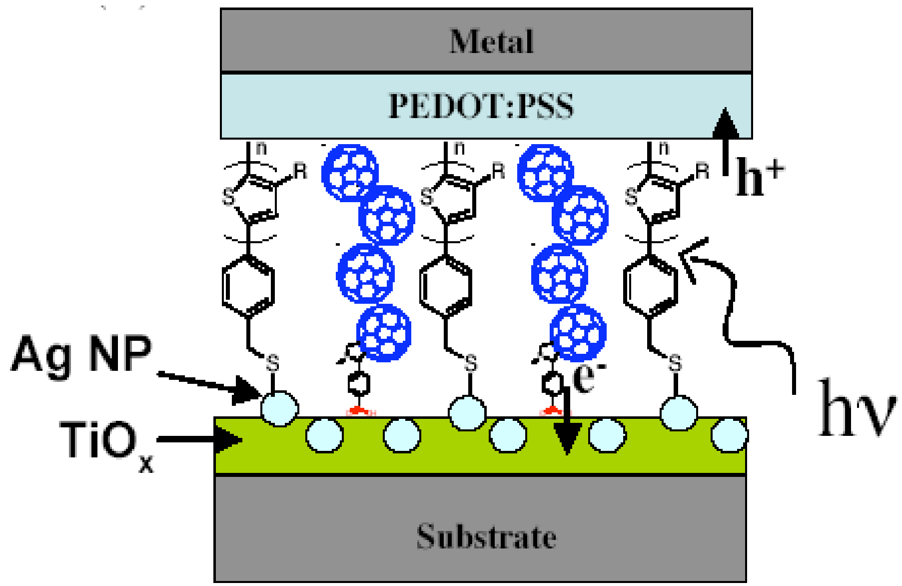
Technologies Addressed

Organic Photovoltaics

Description

Devices with 10nm interdigitated organic nanostructures, where self assembled electroactive molecules will improve performance by reducing interface recombination. Multilayer, solution processible tandem cells are the ultimate goal.

Target Efficiency	10% 2010



Resources ($)

Total Project	DOE Funds	Cost Share
$900,000	**$900,000**	**$0**

Voxtel, Inc.

Dr. David Schut

Optimization of Impact Ionization in Composite Nanocrystal Photovoltaic Devices

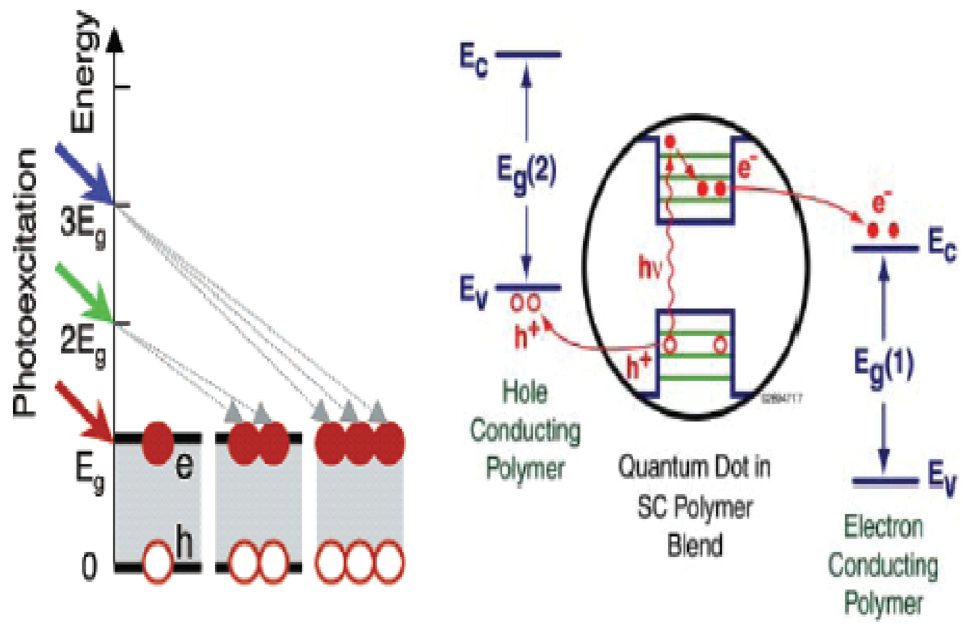
Technologies Addressed

Multiple Exciton Generation

Description

"Janus" nanoparticles incorporated in conducting polymer cells will use multiple exciton generation to go beyond conventional limits in power production.

Target Efficiency	**30%**



Resources ($)

Total Project	DOE Funds	Cost Share
$841,098	**$672,878**	**$168,220**

Wakonda Technologies, Inc.

Dr. Leslie Fritzemeier

Novel Manufacturing of Flexible III-V Thin Films

Technologies Addressed

Advanced Thin Film – Single Junction

Description

Large grain GaAs cells deposited with organo-metallic vapor phase epitaxy on flexible Ge/metal foil substrate instead of expensive Ge wafers.

Target Efficiency	15% by 2010

Resources ($)

Total Project	DOE Funds	Cost Share
$2,103,403	**$892,735**	**$1,210,668**